PROPERTIES OF EXTRUDED WHEAT STARCH - WHEAT GERM MIXTURES AS AFFECTED BY TEMPERATURE, MOISTURE AND LEVEL OF WHEAT GERM

by

MARYSE FAY SCHULTZ

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Approved by:

R Carl Hoseney
Major Professor

TABLE OF CONTENTS

Page

INTRODUCTION

Extrusion is the process of shaping a substance by forcing it through a die (Morris 1981). Extrusion cooking takes this process one step further by using heat and pressure to produce a wide array of products, particularly, expanded snack products. While a large number of extruded snack products have been developed in recent years, a great deal of work remains to be done in this area.

Literature on extrusion is limited, particularly regarding the production of snack type products. There is more literature on the technical aspects of extrusion, such as energy consumption, sheer, and pressure within the extruder (Harper 1981 and Seib 1978); however, little has been published on the effects of moisture and temperature on the extruded product. Of the studies which have been conducted, none have utilized wheat germ as a component of the extrudate.

The purpose of this research was to produce a quality snack product using wheat germ, and to characterize the product's texture as to density, expansion, and breaking strength as influenced by moisture level, temperature, and the level of wheat germ used. Wheat germ was chosen for its nutritive quality, palatability and availability. It is a relatively low cost by-product of the flour milling industry and is growing in consumer acceptance (Shurpalekar and Rao 1977). Wheat starch was chosen as the main component of the extrudate because it is easily extruded and has been previously studied as an extrudate by Faubion et al (1982).

The gravity separation of bran from wheat germ was also studied. Bran reduces the integrity of extruded rods and is thus undesirable. Wheat germ contains a fairly high level of bran as received from most flour mills and must therefore be further purified before extrusion.

LITERATURE REVIEW

Extrusion. Cooking extrusion has been described as a process whereby moistened, starchy, and/or proteinaeous foods are cooked and worked into a viscous, plastic-like dough (Harper 1981). This is commonly accomplished by using a screw extruder consisting of a flighted screw or set of screws which rotate within a sleeve or barrel. This type of extruder uses a viscous-drag mechanism of pumping food material through the barrel of the machine (Seib 1976). The process creates heat and pressure within the barrel because of the resistance to flow of material between the immobile barrel and moving screw. Additional heat can be added by steam injection or heating of jackets surrounding the extruder barrel (Harper 1981). The increase in temperature will also increase pressure within the barrel.

Temperatures as high as 200°C can be reached during extrusion cooking; however, the residence time at those temperatures is usually short (10-15 seconds). Thus, extrusion cooking is often called HTST (high temperature/short-time) cooking (Harper 1981). HTST cooking maximizes beneficial effects of heating such as inactivation of enzymes, improvement of digestion by denaturation of proteins and gelatinization of starch, creation of texture, drying, and sterilization; while minimizing deterimental effects such as browning, destruction of vitamins and essential amino acids, and production of off flavors (Harper 1981 and Seib 1976).

According to Faubion et al (1982), HTST extrusion occurs in three basic phases corresponding to zones within the extruder. The first zone is the feed zone. The basic function of this zone is to convey the feed materials so that they will uniformly fill the screw flights. Some mixing of the feed materials also occurs at this time. Moisture may be added in this zone if the material has not been previously tempered. It is desireable to keep this

zone cool.

Heating is begun in the second, or transition, zone. Pressure, rate of shear and temperature all rise rapidly in this zone. By the end of the transition zone, material is at or above 100°C. In the final, or metering zone, the temperature continues to increase. Further mixing and homogenization occurs as the screw compresses the material and brings it to the die cap as a thermoplastic melt.

As the material is extruded through the die, expansion occurs because of the rapid drop in pressure and concurrent vaporization of the moisture within the product. Discharge pressures typically vary between 30 to 60 atm (Harper 1981). Typically, 7 to 8% moisture will be lost as the pressure drops to normal. The exact amount of moisture lost is dependent upon the temperature at zone 3 and die geometry (Faubion et al 1982). This rapid loss of moisture results in adiabatic cooling of the product. Temperatures may drop to 80°C in a matter of seconds resulting in solidification of the expanded product (Harper 1981).

Extrusion of Starch. Starch is frequently used in producing extruded snack products because it will produce a highly expanded crisp product. According to Conway (1971), 60 to 70% starch is necessary for expansion. Proteinaceous materials can be used to produce porous products as well (Williams 1977); however, starch is preferred in producing expanded snack products.

In studying the effect of extrusion upon the starch of wheat, rice, corn, and waxy corn, it was found that each starch reacts in a slightly different manner (Meuir and Fillet 1975). For instance, waxy corn shows a high expansion ratio when extruded at 135°C, but a lower expansion ratio at 225°C while the other starches increased in expansion as the temperature

was increased. The greatest expansion was observed between 170°C and 200°C for those five cereal starches extruded at 22% moisture. Similar ranges have been reported for wheat starch (Harper 1981). Moisture also affected the expansion of starch with expansion decreasing as moisture was increased (Faubion and Hoseney 1982a).

The texture of starch and flour extrudates have been extensively studied by Faubion et al (1982) revealing that starch extrudates have a large uniform cell structure with smooth walls and few holes or tears. They found that increased moisture decreased cell size and uniformity. Increased force was necessary to shear the extrudate as moisture levels were increased.

Effects of lipid and protein upon starch extrudates. As lipids and protein are added to starch, extrudate characteristics change significantly. One percent free flour lipids will reduce starch extrudate expansion about 3% and produce significant reductions in shear and breaking strength (Faubion et al 1982). The addition of more than 5% oil or high-oil meal will reduce and may prevent expansion (Conway 1971). Monoglycerides and diglycerides reduce the shear and breaking strength of extrudates more than twice as much as free flour lipids at the same level (Faubion 1980).

The effect of protein on starch extrudates depends upon the type and concentration of protein used (Faubion et al 1982). At levels up to 3%, gluten exerted no noticeable effect upon expansion; however, breaking strength was significantly reduced (Faubion and Hoseney 1982b). As gluten levels were increased further, a decrease in expansion was found. The lowest expansion was at 11% gluten. Expansion increased as gluten levels increased above 11%. Breaking strength reached a minimum at 12% gluten. When soy protein isolate (SPI) was added to starch an increase in diameter was observed at levels of 1 to 10% SPI (Faubion and Hoseney 1982b). Shearing and

breaking strengths were below those of gluten-starch extrudates at 1 to 3% SPI, but increased with increasing SPI, reaching levels near that of pure starch. Adding both SPI and flour lipids was found to decrease expansion slightly and decrease breaking strength significantly when compared to the effects of SPI alone (Faubion et al 1982).

Wheat Germ. Wheat germ is a unique source of highly concentrated nutrients. It contains 3 times as much protein, seven times as much fat, fifteen times as much sugar, and six times the mineral content of white flour (Shurpalekar and Rao 1977). Raw wheat germ contains the antinutritional factors hemagglutinin and antitrypsin; however, both of these may be destroyed by heat treatment such as toasting or autoclaving (Pomeranz et al 1970). Toasting was found to improve net protein utilization (NPU) while prolonged autoclaving reduced NPU and destroyed lysine, cystine, and arginine. Biological methods of nutritional evaluation reviewed by Shurpalekar and Rao (1977) showed that the protein efficiency ratio (PER) for wheat germ was as good as that of animal proteins when diets contained at least 5% protein. The PER for wheat germ was highest when diets contained 10% protein. The PER at 10% was 2.87 as compared to a PER of 2.84 for nonfat dry milk solids.

The only drawback to extensive utilization of wheat germ is its poor storage stability. This is because of the high levels of fat and protein along with lipase, lipoxidase, and protease. Various methods to improve shelf-life have been reviewed by Shurpalekar and Rao (1977). These are: storage at moisture levels of about 5%, low temperature (less than 10°C), packing under inert gases or vacuum, and heat treatment during processing. These have been reported to significantly increase shelf-life. Storage of up to 33 months without loss of fresh taste has been reported for wheat germ

dried down to 5% moisture.

Specific Gravity Separation. According to promotional literature from Triple/S Dynamics (1980a), the Fluidized-Bed Separator, more commonly known as the "gravity separator", can make a highly sensitive dry separation on the basis of density, size, or shape. Lockwood (1945) states that separation according to specific gravity is achieved by floating the particles to be separated on a film of air over a perforated and rapidly oscillating table or deck. Both lateral and longitudinal pitches are adjustable and air supply and oscillation can be regulated according to the separation required.

Separation is achieved as the air flow forms a stratification of particles above the deck with the lightest particles forming the top layer. As the deck oscillates the heavy particles are kicked to the high side of the deck with the light particles staying on the low side (Oliver Mfg. Co., 1979). The apparent "heaviness" of the particle is actually a combination of size, density, and shape. Thus, to achieve good separation, it is necessary for two of the factors to be controlled within certain limits (Triple/S Dynamics 1980[b]). For example, if two particles of different densities are to be separated, it is necessary that the denser one not have such a great surface area that it appears "lighter" than the less dense particles.

MATERIALS AND METHODS

Preparation of Wheat Germ-Wheat Starch Mixtures. Commercial grade wheat starch (Midwest Solvents, Inc., Atchison, Kansas) at 10.0% moisture and ground stablized wheat germ (AnaCon Foods), at 7.1% moisture, 34.6% protein, 11.2% fat, and 4.7% ash were combined at levels of 0, 10, 15, 20, 25, and 30% wheat germ on a dry matter basis. These were mixed by hand until they appeared uniform and then shaken in a plastic bag for 3 min. The mixtures

were then tempered in a rotating drum using aspirated water as described by Faubion (1980) to moisture levels of 16, 17, 18, 19, 20, 20.5, and 22% moisture on a wet basis. Only 18% moisture was used with temperature variations. The tempered mixtures were allowed to equilibrate overnight before extruding.

Extruder Settings. A Brabender laboratory size single screw extruder, model #2403, was used for extrusion. This extruder has 3 zones which may be heated and air-cooled separately. The feed zone (1) was set at 30°C, the middle zone (2) at 100°C, while the end zone (3) was varied from 125°C to 200°C. Zone 3 was set at 175° while studying moisture variations. When zone 3 temperature was increased, the temperature at the other zones also tended to increase, reaching temperatures as high as 141°C at zone 2 and 36°C at zone 1 when zone 3 was set at 195°C. The screw used has a 1:4 compression ratio and was rotated at a speed of 100 rpm.

Dies. Three different dies were used: a 9 mm diameter straight die, a 7 mm diameter straight die, and a die with a square side opening 7 mm on each side. The side die was constructed so that the extrudate was forced to make a 90° turn before being extruded through the square opening. The respective areas of the openings were 0.38 cm^2, 0.64 cm^2, and 0.49 cm^2. The products collected from all dies were cylindrical in shape.

Start-up Procedure. The extruder was started up with zone 3 at 175°C, zones 1 and 2 were set at the temperatures stated above. This start-up procedure is adapted from that used by Faubion and Hoseney (1982b). Moist corn meal was used for the start-up. Then flour, at a moisture level of about 20%, was extruded while zone 3 was set to the desired temperature. After this temperature had been reached, the wheat germ-wheat starch mixtures were extruded. The extruder was fed by hand rather than automatically due to

the tendency of the tempered mixtures containing wheat germ to bridge, stopping the flow of material through the feeder.

Measurement of Extrudates. As the mixture was extruded, rods about 1 meter in length were collected. Five to 8 rods were collected for each variation depending on the fragility of the rods. The first 2 rods extruded from each variation were not collected in order to prevent contamination from the previous run. The collected rods were cut into pieces 15 cm in length and dried for 30 min at 100°C. Ten rods were selected at random for measurement. Measurement techniques are as specified by Faubion (1980). Expansion was measured as the average diameter of the 10 rods. Each rod was measured with calipers 1 cm from each end. Density was calculated using the weight of 10 rods divided by the calculated volume of the 10 rods. The force to break each rod was measured using an Instron model 1130 Universal Texture Analyzer. The rod was suspended over a 9 cm expanse supported at each end and broken in the middle by a driven rod 2 cm in diameter. The amount of force used to break the rod was recorded in kilograms.

Gravity Separation. A preliminary study of possible methods for purification of wheat germ included: air classification, sifting, and gravity separation. Gravity separation was chosen as the most feasible method for continued study. This study was conducted in four steps, with the number and/or range of variable settings for the gravity separator being decreased with each step.

The gravity separator used was the Sutton Steel and Steel laboratory model V135A Fluidized-Bed Separator. This machine had variable air flow, oscillation, and feeding speed. The slope of the deck could be adjusted both laterally and longitudinally. The feed out gate could be adjusted to obtain either two or three fractions by means of two metal plates which were fixed

on pivots within the gate.

Although an infinite number of settings were possible for each machine control, each range was divided into increments. Feeding rate had standard settings, 1 through 10. The end slope (longitudinal slope) and side slope (lateral slope) could be adjusted by raising or lowering the deck 9.2 cm and 6.4 cm, respectively. These distances were divided into 6 increments with 0 being the base level and 5 being maximum slope. Air flow and eccentric speed (oscillation) were recorded as "turns" with each turn being one clockwise revolution of the control knob. Eccentric speed could be adjusted from 0 to 25 turns, air flow from 0 to 70 turns. The feed out gate was divided into six equal portions with the inner divisions labelled A, B, C, D, and E from left to right. The left side was the low side of the deck.

The purpose of the first study was to determine the range of settings where separation of wheat germ from bran was possible. All six variables were used. Positions 1, 3, and 5 of both the end slope and side slope were combined to obtain 9 settings. At each of those settings, air flow and eccentric speed were adjusted to obtain separation of the wheat germ on the deck. At each setting, air flow then eccentric speed were adjusted until separation was no longer obtained. In other words, the wheat germ either left the deck on the low side, left the deck on the high side, or would not move on the deck. Feeding speed was adjusted to keep the deck full as specified by the operation manual (Triple/S Dynamics 1980). Gate positions were adjusted for only two fractions because it was found that the middle fraction (which was automatically recycled) could not be reseparated because the recycling system pulverized the germ into a fine powder. Thus the two gates were placed at the demarcation between germ and bran fractions.

RSM (4 variables). For the second study the feeding speed was set at

7. The gate was set at the demarcation between bran and germ which was the B position (1/3 of the way from the left hand side). A response surface method plan for four independent variables (Cochran and Cox 1957) was used to determine the settings for the 4 remaining variables within the following ranges: air flow, 12 to 18 turns; eccentric speed, 3 to 15 turns; side slope position, 3 to 5; and end slope position, 3 to 5 (Table 1). The trial order was randomized to eliminate bias. Also to eliminate bias, controls were returned to the zero, or base position between trials.

The deck was cleared of wheat germ before each trial. After the controls were set, the gravity separator was run about 3 min to load the deck with wheat germ. The machine was then turned off and plastic bags were secured with rubber bands under both feed out spouts. The machine was then started up again and run for 10 min. Commercial grade wheat germ (International Multi-Foods Corp., Kretchmer Prod. Div.) with a protein level of about 30% dry basis was used. Care was taken to maintain a steady level of germ in the vibratory feeder. The bran and germ fractions were weighed and recorded as the percent of the weight of the germ fraction over the weight of the total sample. The germ fraction was analyzed for protein, moisture, fat, and ash levels at the Kansas State University Grain Science Analytical Laboratory.

The effect of the four independent variables (air flow (AIR), eccentric speed (ECSP), side slope (SS), and end slope (ES)) upon each of the four dependent variables (percent purified germ/total germ, (GM) and the percent protein (PROT), ash (ASH), and fat (FAT) in the purified germ) was calculated using SAS computer analysis response surface regression. Predicted values were plotted according to the following expanded Taylor series equations:

Table 1. Gravity Separation of Wheat Germ for RSM: Machine Settings as Specified for 4 Variable Plan.

	Machine Settings				Analysis of Purified Germ			
Trial	ES[a/]	SS	ECSP	AIR	GM[b/]	PROT	ASH	FAT
Control	---	---	---	---	---	30.58	5.1	10.0
1	4.0	4.0	9	12.0	98.63	30.28	5.0	10.3
2	4.5	4.5	12	13.5	89.64	31.92	5.0	9.9
3	4.0	4.0	9	15.0	91.33	31.41	5.1	10.4
4	3.5	4.5	6	16.5	81.68	31.99	5.0	10.7
5	4.0	4.0	15	15.0	82.41	31.41	5.0	10.4
6	3.5	4.5	12	16.5	73.69	31.99	5.0	10.4
7	4.0	4.0	9	15.0	93.14	31.54	5.0	10.2
8	3.5	3.5	6	13.5	97.59	30.56	5.0	10.1
9	4.5	3.5	12	13.5	93.65	30.63	5.0	10.2
10	5.0	4.0	9	15.0	81.45	32.10	5.0	10.7
11	4.5	3.5	6	16.5	91.16	31.73	5.1	10.5
12	4.0	4.0	9	15.0	94.30	30.62	5.0	10.4
13	4.5	4.5	12	16.5	49.06	31.26	4.9	10.5
14	3.5	4.5	6	13.5	96.86	30.20	5.0	10.2
15	3.5	4.5	6	13.5	85.95	30.62	5.0	10.5
16	3.0	4.0	9	15.0	96.88	32.01	5.1	10.1
17	4.5	3.5	6	13.5	95.97	31.42	5.0	10.1
18	3.5	3.5	12	16.5	74.24	30.70	5.0	10.3
19	4.0	4.0	9	15.0	89.67	32.13	5.0	10.2
20	4.5	4.5	6	16.5	96.11	31.94	4.9	10.4
21	4.0	4.0	3	15.0	94.87	32.60	5.0	10.3
22	4.5	4.5	6	13.5	94.35	30.75	5.0	10.2
23	4.0	4.0	9	15.0	93.61	31.15	4.8	10.7
24	4.0	4.0	9	18.0	53.56	31.70	5.0	10.7
25	4.5	3.5	12	16.5	40.13	32.71	5.0	10.7
26	3.5	3.5	12	13.5	95.68	32.64	5.0	10.3
27	3.5	3.5	12	13.5	96.46	31.12	5.0	10.4
28	4.0	4.0	9	15.0	90.78	31.01	5.0	10.3
29	4.0	3.0	9	15.0	91.61	31.56	5.0	10.4
30	4.0	4.0	9	15.0	89.24	31.62	5.0	10.5
31	4.0	5.0	9	15.0	90.87	31.12	5.0	10.6

[a/]Independent variables: ES (end slope), SS (side slope), ECSP (eccentric speed), AIR (air flow)

[b/]Dependent variables: GM (% purified germ/total), PROT (% protein - dry basis), ASH (% ash - dry basis), FAT (% fat - dry basis)

$$GM = -569.0498 + 70.3675(ES) - 23.8242(SS) + 35.1113(ECSP) + 64.8089(AIR) - 3.3108(ES)^2 + 3.2550(ES*SS) - 1.2358(SS)^2 - 3.4625(ES*ECSP) + 0.2842(SS*ECSP) - 0.1066(ECSP)^2 - 2.1767(ES*AIR) + 1.2200(SS*AIR) - 1.5061(ECSP*AIR) - 1.8201(AIR)^2$$

$$PROT = 21.5740 - 1.3567(ES) - 4.6625(SS) + 1.5418(ECSP) + 1.6833(AIR) + 0.3458(ES)^2 + 0.2000(ES*SS) - 0.3692(SS)^2 - 0.1917(ES*ECSP) + 0.0525(SS*ECSP) + 0.0082(ECSP)^2 - 0.0050(ES*AIR) + 0.4067(SS*AIR) - 0.0722(ECSP*AIR) - 0.0799(AIR)^2$$

$$ASH = -17.0719 - 0.6708(ES) + 8.4542(SS) + 0.9549(ECSP) + 0.2042(AIR) + 0.2792(ES)^2 - 1.4250(ES*SS) + 0.2292(SS)^2 - 0.2292(ES*ECSP) + 0.2292(SS*ECSP) + 0.0064(ECSP)^2 + 0.4417(ES*AIR) - 0.4750(SS*AIR) - 0.0764(ECSP*AIR) + 0.0255(AIR)^2$$

$$FAT = 32.2531 + 1.2042(ES) - 8.6208(SS) - 0.9257(ECSP) - 0.3792(AIR) - 0.3208(ES)^2 + 1.3750(ES*SS) - 0.2208(SS)^2 + 0.2792(ES*ECSP) - 0.2958(SS*ECSP) - 0.0103(ECSP)^2 - 0.4750(ES*AIR) + 0.5417(SS*AIR) + 0.0847(ECSP*AIR) - 0.0245(AIR)^2$$

Three dimensional and contour plots were utilized in evaluating the best settings for germ purification.

RSM (2 variables). The third study attempted to eliminate some of the error found in the 4 variable RSM. Greater care was taken in laboratory analyses of protein, ash, and fat. The range of the variables was decreased as well. End slope and side slope were both set at 4.5. An RSM 2 variable plan (Cochran and Cox 1957) was used to determine points to be run for

eccentric speed in range of 9 to 18 turns. Seven settings were added to the 13 that the 2 variable plan called for to make a total of 20 settings (Table 2). Predicted values were plotted according to the following expanded Taylor series equations:

$$GM = 531.8717 - 19.5008(ECSP) - 22.2915(AIR) - 0.1229(ECSP)^2 + 1.0326(ECSP*AIR) - 0.1763(AIR)^2$$

$$PROT = -62.8366 + 1.9526(ECSP) + 9.4930(AIR) - 0.000392(ECSP)^2 - 0.1125(ECSP*AIR) - 0.2258(AIR)^2$$

$$ASH = 11.3409 - 0.2204(ECSP) - 0.5334(AIR) + 0.00446(ECSP)^2 + 0.005454(ECSP*AIR) + 0.0133(AIR)^2$$

$$FAT = 11.6141 + 0.5479(ECSP) - 0.7146(AIR) - 0.001907(ECSP)^2 - 0.02606(ECSP*AIR) + 0.03218(AIR)^2$$

Only contour plots were utilized in evaluating the data from this study. Other than the above mentioned changes, the 2 variable study was done by the same method as the 4 variable gravity separation.

<u>4th Study</u>. The air flow was reduced to between 16 and 17 turns and eccentric speed to between 8 and 11 turns in accordance with optimal ranges for protein and germ recovery as predicted by the 2 and 4 variable RSM studies. This study was run by the same method as the previous three; however, data was plotted for protein and % germ fraction according to eccentric speed and air flow by hand rather than using computer analysis. The following (eccentric speed, air flow) values were used: (8,16), (8,17),

Table 2. Gravity Separation of Wheat Germ for RSM: Machine Settings as Specified for 2 Variable Plan.

	Machine Settings		Analysis of Purified Germ			
Trial	ECSP[a/]	AIR	GM[b/]	PROT	ASH	FAT
Control	---	---	---	30.3	5.3	9.8
1	14.0	17.0	42.8	34.2	5.2	9.8
2	11.5	18.5	33.5	34.0	5.2	9.6
3	16.5	15.5	38.2	32.6	5.2	10.0
4	14.0	14.9	93.5	32.6	5.2	10.0
5	11.5	17.0	42.3	34.0	5.2	9.9
6	16.5	18.5	13.5	33.3	5.2	9.7
7	14.0	17.0	45.5	34.1	5.3	9.6
8	14.0	17.0	55.9	33.9	5.2	9.9
9	17.5	17.0	53.8	33.3	5.2	10.1
10	14.0	17.0	57.2	33.7	5.2	10.2
11	14.0	17.0	56.4	33.7	5.2	9.9
12	14.0	19.1	17.7	33.1	5.2	10.1
13	14.0	17.0	52.5	33.7	5.2	10.3
14	10.5	19.1	40.9	33.7	5.3	10.2
15	10.5	14.9	98.4	31.3	5.3	9.8
16	17.5	14.9	40.2	33.9	5.3	10.4
17	17.5	19.1	4.7	32.9	5.4	10.1
18	13.0	14.9	95.8	31.6	5.4	9.6
19	9.0	16.0	94.3	32.5	5.4	9.3
20	9.0	18.0	58.4	34.4	5.3	9.7

[a/]Independent variables: ECSP (eccentric speed), AIR (air flow), end slope and side slope set at 4.5

[b/]Dependent variables: GM (% purified germ/total), PROT (% protein - dry basis), ASH (% ash - dry basis), FAT (% fat - dry basis)

(9,16), (9,16.5), (9,17), (10,16), (10,16.5), (10,17), (11,16), and (11,17). Actual values obtained were compared to those predicted by RSM.

Finally, points in the range of 7 to 10 eccentric speed and 15.75 to 17 air flow were selected to maximize protein and germ recovery according to the results of the fourth study. These points were (7,16.75), (8,16.5), (8.5,17), (9,16.25), (9.25,16.25), (9.5,15.75), and (9.5,16). Two other points were run as well and these were (10,14.5) and (8.5,14). The former was selected at an eccentric speed of 10 since this value gave optimal purity; then the germ recovery was maximized by air flow. The latter point was chosen for its high germ recovery (almost no germ is present in the bran fraction as evaluated by observation).

RESULTS AND DISCUSSION

Extrusion

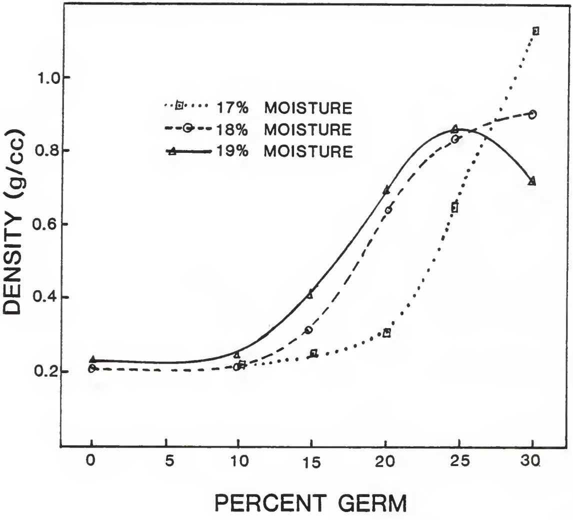
Extrusion Parameters. The parameters for moisture level, germ content, and temperature were determined by the ability of the extruder to operate reliably and produce cohesive rods. It was found that temperature, moisture level, and germ level are interactive, with high germ level, high temperature, and high moisture all tending to produce an uneven flow of extrudate from the die, referred to as surging, while low temperature, low moisture, and low germ content tend to exceed the power limits of the extruder. The upper limit for wheat germ content was about 30% when other conditions were ideal. Above this level of wheat germ, product tended to surge from the die in small pieces rather than in cohesive rods. The ideal moisture level for wheat germ-wheat starch mixtures was in the range of 16 to 19%, with lower moisture tending to cause less surging in high germ mixtures. Pure starch could not be extruded at 16 or 17% moisture without

exceeding the power limitations of the extruder.

Evaluation of Dies. Of the dies used, the side die was most effective in reducing the tendency toward surging without exceeding power requirements of the extruder. Surging was observed at germ levels as low as 15% germ with 19% moisture using the 9 mm die while the side die could easily handle 25% germ. Extrusion was also possible at high germ levels using the 7 mm straight die; however, at low germ levels the power requirements for the machine were frequently exceeded. Further study is needed to determine whether the advantages of the side die are due to differences in design or due to the size of the orifice, which is greater than that of the 7 mm straight die but smaller than that of the 9 mm die.

Results of Moisture and Temperature Variations - Effects Upon Density. The density of the extruded rods changes very little from 0 to 10% germ, but increases dramatically as the germ level is increased from 10 to 25% (Fig. 1). Using 30% germ, a decrease was noted at 18 and 19% moisture. This was probably caused by difficulty in accurately measuring the volume of rods which had surged during extrusion. Moisture and temperature affect density to a lesser extent with density showing a slight decrease as temperature increases at most germ levels (Table 3). This increase in density is more significant at 0 and 10% germ levels were standard deviation ranges from 0.01 to 0.10 than at higher germ levels where the standard deviation becomes as high as 0.28. Standard deviation is determined as $\sqrt{\sum(\bar{X}_i - X^2)/n-1}$. Each average was determined from a minimum of three trials unless otherwise noted, as many as five trials were run in some cases to reduce error caused by surging. Within the optimal range of moisture levels (17 to 19% moisture), changes in density do not appear to be significant for the 9 mm straight die (Table 4), while for the side die a slight increase in density is noted as the moisture level is

Fig. 1. Effect of moisture on density of wheat germ-wheat starch rods extruded at zone 3 temperature of 175°C, using 7 mm side die.



DENSITY (g/cc)
1.0
0.8
0.6
0.4
0.2
17% MOISTURE
18% MOISTURE
19% MOISTURE
0
5
10
15
20
25
30
PERCENT GERM

Table 3. Average Density in g/cc of Wheat Germ - Wheat Starch Rods Extruded at 18% Moisture Using 7 mm Side Die.

Temp°C Zone 3	Percent Germ 0	10	15	20	25
150	0.27	0.32	0.42	0.53	0.87
165	0.25	0.27	0.35	0.59	0.90
180	0.22	0.24	0.37	0.54	0.80
195	0.19	0.23	0.37	0.46	0.57

Table 4. Average Density in g/cc of Wheat Germ - Wheat Starch Rods Extruded at 175°C Using 9 mm Straight Die.

Percent Moisture	Percent Germ 0	10	20	30
16	---	0.30	0.76	0.80
17	---	0.27	0.85	0.98
18	0.22	0.26	0.72	0.97
19	0.24	0.27	0.61	---

increased from 17 to 19% moisture (Table 5). As with temperature variation, the increase in density was more significant at lower germ levels because the standard deviation was lower at those levels. At 25% germ, the observed increase was less than the standard deviation which was in the range of 0.10 to 0.16. The lack of a clear trend using the 9 mm die may be due to the inherent difficulties in accurately calculating the volume of extruded rods which have experienced excessive surging. Also, only two trials at each level were run using the 9 mm die.

Results of Moisture and Temperature Variation - Effects Upon Expansion. The expansion of the rods decreased as the germ level increased with the exception of 10% germ which increased at 18% and 19% moisture with zone 3 temperatures ranging from 165 to 180°C when using the side die (Table 6 and 7). This increase was seen at 19% moisture using the 9 mm die and at 20.5% moisture using the 7 mm die; however, several more duplications would be needed to confirm the data using the 7 and 9 mm die (Table 8 and 9). A similar expansion is noted by Faubion and Hoseney (1982a) using starch and 8% soy protein isolate. The expansion of the rods decreased as the temperature was increased except at the 10% germ level where expansion was greater than that seen at 150°C. Decreasing expansion coincided with decreasing density as affected by both moisture and temperature. This apparent anomaly was due to increased expansion in the lengthwise direction. Measurement of the rate of extrusion showed that the rods did extrude at greater rates as temperature was increased above 165°C (Table 10).

Results of Moisture and Temperature Variation - Effect Upon Breaking Strength. The force needed to break a rod decreased as the temperature was increased and moisture levels were decreased (Table 11 & 12). No clear trend was observed in breaking strength as germ level increased. This may be due,

Table 5. Average Density in g/cc of Wheat Germ-Wheat Starch Rods Extruded at 175°C Using 7 mm Side Die.

Percent Moisture	Percent Germ 0	10	15	20	25	30
17	---	0.22	0.25	0.31	0.71	1.13
18	0.21	0.22	0.32	0.65	0.84	0.92
19	0.23	0.23	0.42	0.68	0.86	0.82

Table 6. Average Diameter in mm of Wheat Germ - Wheat Starch Rods Extruded at 18% Moisture Using 7 mm Side Die.

Temp°C Zone 3	Percent Germ 0	10	15	20	25
150	14.6	13.6	12.2	10.8	10.3
165	13.6	13.8	12.1	10.5	8.9
180	12.5	13.7	11.4	9.2	7.3
195	10.3	10.3	9.5	8.0	6.2

Table 7. Average Diameter in mm of Wheat Germ-Wheat Starch Rods Extruded at 175°C Using 7 mm Side Die.

Percent Moisture	Percent Germ 0	10	15	20	25	30
17	---	13.25	12.15	12.01	8.17	5.7
18	12.23	12.69	10.93	8.99	7.69	6.4
19	11.45	12.69	10.46	8.73	7.42	5.1

Table 8. Average Diameter in mm of Wheat Germ-Wheat Starch Rods Extruded at 175° C, Zone 3, Using 7 mm Straight Die and 3-1 Screw.

Percent Moisture	Percent Germ 0	10	20	30
18.0	12.6	11.0	9.9	6.8
19.0	11.0	10.9	7.2	6.7
20.5	9.4	11.0	7.9	7.1
22.0	8.6	7.8	7.2	6.9

Table 9. Average Diameter in mm of Wheat Germ-Wheat Starch Rods Extruded at 175° C, Zone 3, Using 9 mm Straight Die.

Percent Moisture	Percent Germ 0	10	20	25	30
17	---	12.7	9.3	7.9	7.9
18	13.6	12.8	8.6	8.1	8.6
19	13.8	11.1	---	---	---

Table 10. Linear Velocity of Extrudate in M/min of Wheat Germ-Wheat Starch Rods at 18% Moisture Using 7 mm Side Die.

Temp°C Zone 3	Percent Germ 0	10	15	20	25
150	1.21	1.20	1.46	1.40	1.62
165	1.41	1.20	1.40	1.48	1.33
180	2.10	1.80	1.97	1.79	2.04
195	3.06	3.30	2.36	3.92	4.00

Table 11. Average Force in Kg to Break Extruded Wheat Starch Rods Over a 9 cm Expanse.

Temp °C Zone 3	Percent Germ 0	10	15	20	25
150	3.3	2.5	3.5	3.4	3.2
165	2.5	2.6	2.8	3.1	2.4
180	1.4	1.7	1.5	1.5	1.0
195	0.6	0.9	1.0	0.8	0.4

All rods extruded at 18% moisture using 7 mm side die.

Table 12. Average Force in Kg to Break Wheat Germ-Wheat Starch Rods Extruded at 175°C Using 7 mm Side Die Over a 9 cm Expanse.

Percent Moisture	Percent Germ 0	10	15	20	25	30
17	---	1.1	1.1	1.0	1.3	0.6
18	1.2	1.3	1.2	1.5	1.1	0.6
19	1.5	1.4	1.7	1.7	1.0	0.4

in part, to the high standard deviation which ranged from 0.28 to 0.69 kg. In general, the breaking strength tends to increase up to a germ level of about 20% then decreases. A definite decrease was seen between 25% and 30% germ at all moisture levels (Table 12). Using the 9 mm die at 175°C, the force first increased at 10% germ then decreased (Table 13). Using the side die at temperatures from 150°C to 195°C, differing trends were observed as germ level was increased at different temperatures (Fig. 2).

Decrease in breaking strength appears to be caused by three factors: decrease in apparent density, decrease in diameter, and decrease in the structural integrity of the rod. As the temperature of zone 3 increased the diameter and density of the extrudate decreased dramatically, while the rate of extrusion increased. Thus, as the temperature increased, the grams of extrudate per meter decreased (Table 14). Breaking strength decreased as the amount of material being broken decreased with increasing temperature at each specific germ level. This relationship between grams of extrudate per meter and breaking strength was also observed as moisture levels decreased at each specific germ level up to 25% germ (Table 15). The grams of extrudate per meter tended to increase as germ levels were increased up to about 20% germ, however breaking strength did not correspond in this instance. While rods increased in grams of extrudate per meter and in density as germ levels were increased, they also decreased in diameter and above 20% germ in integrity as well. Above 20% germ, a decrease in breaking strength was observed at all temperatures.

While the force to break the rods first increased then decreased as germ levels increased, the rigidity of the rod, as measured by observation, increased. At 10% germ and 175°C, a rod was easily crushed between the fingers but usually would not break when dropped. However at 10% germ, the

Table 13. Average Force in Kg to Break Wheat Germ-Wheat Starch Rods Extruded at 175°C Using 9 mm Straight Die.

Percent Moisture	Percent Germ 0	10	20	30
16	---	2.0	0.8	0.6
17	---	1.7	1.8	0.6
18	1.2	1.4	0.9	0.8
19	1.2	1.5	0.7	---

Fig. 2. Effect of temperature on breaking strength of wheat germ-wheat starch rods extruded at 18% moisture using 7 mm side die.

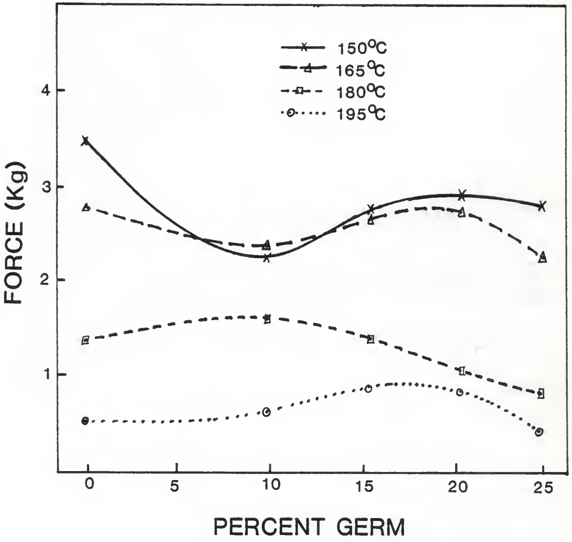

150°C
165°C
180°C
195°C
FORCE (Kg)
4
3
2
1
0
5
10
15
20
25
PERCENT GERM

Table 14. Grams of Extrudate per Meter of Wheat Germ-Wheat Starch Rods Extruded at 18% Moisture Using 7 mm Side Die.

Temp°C Zone 3	Percent Germ 0	10	15	20	25
150	47.4	47.2	48.2	47.1	55.6
165	34.9	39.4	42.2	50.0	48.4
180	26.1	30.8	37.7	35.7	33.9
195	15.7	19.5	26.3	22.6	28.5

Table 15. Grams of Extrudate per Meter of Wheat Germ-Wheat Starch Rods Extruded at 175°C Using 7 mm Side Die

Percent Moisture	Percent Germ 0	10	15	20	25	30
17	---	29.6	29.7	27.2	37.7	32.3
18	23.8	29.8	31.6	41.2	39.2	40.0
19	28.6	31.5	35.7	40.6	37.4	33.6

rod was too rigid to be crushed but will break into many pieces if dropped. The main effect of this textural difference regarding edibility was that at low germ levels the product was more friable while at higher germ levels the product was more crunchy. Temperature also affected this parameter with low temperatures producing more rigid rods.

Gravity Separation

First Study. Gravity separation of wheat germ was possible with side slope and end slope set at any position; however, separation was much better when positions of 3 or higher were used. At those settings separation was possible with eccentric speeds of 0 to 20 turns and air flow of 12 to 18 turns.

RSM 4 Variables. Over the range studied only the percent purified germ could be predicted with accuracy as indicated by the R-square values obtained. The R-square value for percent purified germ was 0.913 as compared to values of 0.482 for protein, 0.556 for ash and 0.516 for fat. These low R-square values were most likely due to error in laboratory analyses of protein, ash, and fat. Duplicates of several samples were run, showing as much deviation between duplications as there was between separate samples. A second analysis of the samples showed only slight improvement. The problem was thoroughly discussed with the technicians running the analyses before further samples were run.

In order to further reduce error, predicted values were compared to actual values for each data value. Error increased as end slope, side slope, and eccentric speed approached their lower limits. Probability values (Table 16) for purified germ (which was considered most accurate in view of R-square values) indicated that end slope and side slope had far less influence upon

Table 16. Probability of Influence of Independent Variables Upon Dependent Variables as Determined by SAS Response Surface Regression for 4 Variable Plan.

Variable	GM	PROT	ASH	FAT
ES	0.0121	0.6795	0.2144	0.3297
SS	0.9723	0.7415	0.1863	0.2505
ECSP	0.0001	0.4896	0.2068	0.2228
AIR	0.0001	0.1789	0.2118	0.3800

Independent Variables: ES (end slope), SS (side slope), ECSP (eccentric speed), AIR (air flow)

Dependent Variables: GM (% purified germ/total), protein, ash, and fat are determined from purified germ.

Note: Statistical significance of independent variables influence increases as probability goes to zero.

germ recovery than air flow or eccentric speed. Therefore, side slope and end slope were set at 4.5 for further study. It was also determined that the lower limit for the eccentric speed could probably be moved from 3 to 9 in order to reduce error without losing the ideal separation range.

RSM 2 Variables. The R-squared values obtained from the 2 independent variable RSM were 0.849 for percent germ recovery, 0.822 for protein, 0.527 for ash, and 0.495 for fat. This was an improvement for protein and a slight decrease for other variables. It was probable that the error seen for ash and fat was due to the inability of laboratory methods to accurately determine differences as small as those seen between the purified wheat germ from various separations. Ash varied only from 5.2% to 5.4% and fat varied only from 9.3% to 10.3% (Table 2). Error in these determinations usually falls within 0.2 to 0.3%; this normally small error becomes very large over such a small range. The range for protein was from 30.3% to 34.4%, making protein the most reliable method of determining the purity of the germ recovered. Probability values (Table 17) show that air flow had the most significant influence upon both percent germ recovered and the purity of the germ as determined by protein.

Predictions based on contour plots for protein and precent germ recovered (Figs. 3 to 7) indicated that a protein level of 32% or better could be obtained with 80% germ recovery by using eccentric speeds in the range of 9 to 11 with air flow set at 16 to 17. It was expected that germ recovery might fall somewhat short of the predicted value because predictions indicated that recoveries as high as 123% could be made (Fig. 4). Contour plots from the 4 variable study (Figs. 5-7) were used in conjunction with 2 variable plots for predicting germ recovery.

4th Study. When separations were run over the ideal predicted range, 9

Table 17. Probability of Influence of Independent Variables Upon Dependent Variables as Determined by SAS Response Surface Regression for 2 Variable Plan.

Variable	GM	PROT	ASH	FAT
ECSP	0.0014	0.0028	0.0499	0.0313
AIR	0.0001	0.0001	0.1259	0.1658

Independent Variables: ECSP (eccentric speed), AIR (air flow)

Dependent Variables: GM (% purified germ/total), protein, ash, and fat are determined from purified germ.

Note: Statistical significance of independent variables influence increases as probability goes to zero.

Fig. 3. Predicted values of percent protein as affected by eccentric speed and air flow for wheat germ purified on a Fluidized-Bed Separator using side slope and end slope of 4.5.

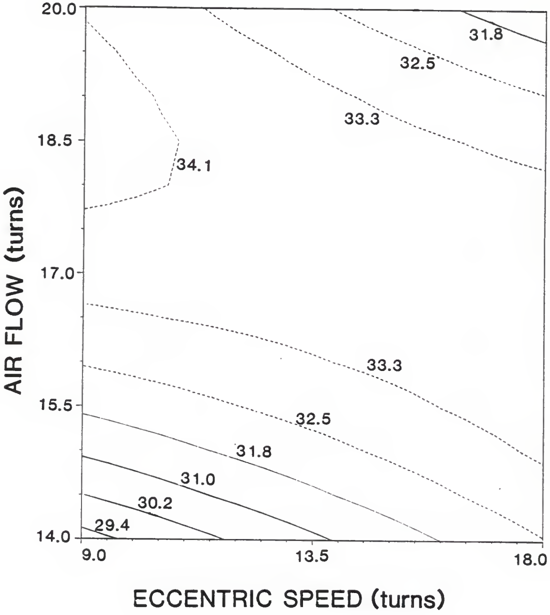

20.0
18.5
17.0
15.5
14.0
AIR FLOW (turns)
9.0
13.5
18.0
ECCENTRIC SPEED (turns)
31.8
32.5
33.3
34.1
33.3
32.5
31.8
31.0
30.2
29.4

Fig. 4. Predicted values of percent germ recovered as affected by eccentric speed and air flow for wheat germ purified on a Fluidized-Bed Separator using side slope and end slope of 4.5.

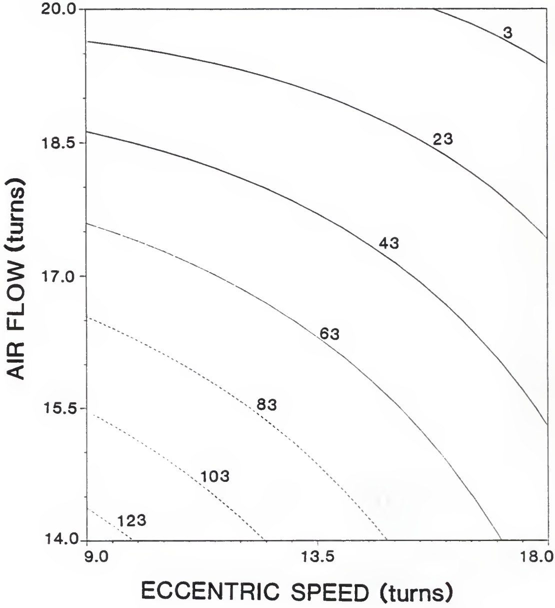

20.0
18.5
17.0
15.5
14.0
9.0
13.5
18.0
AIR FLOW (turns)
ECCENTRIC SPEED (turns)
3
23
43
63
83
103
123

Fig. 5. Predicted values of percent germ recovered as affected by eccentric speed and end slope for wheat germ purified on a Fluidized-Bed Separator using side slope and end slope of 4.5 and air flow of 15.

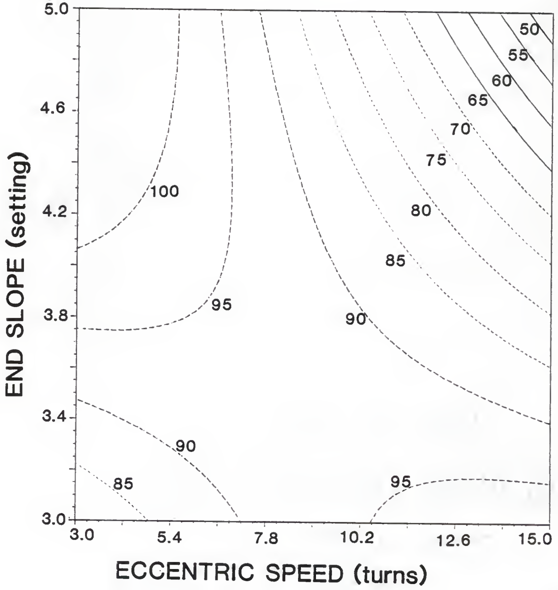
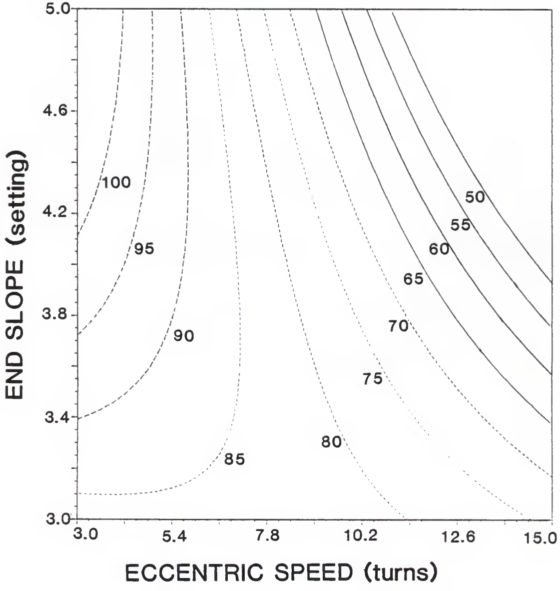
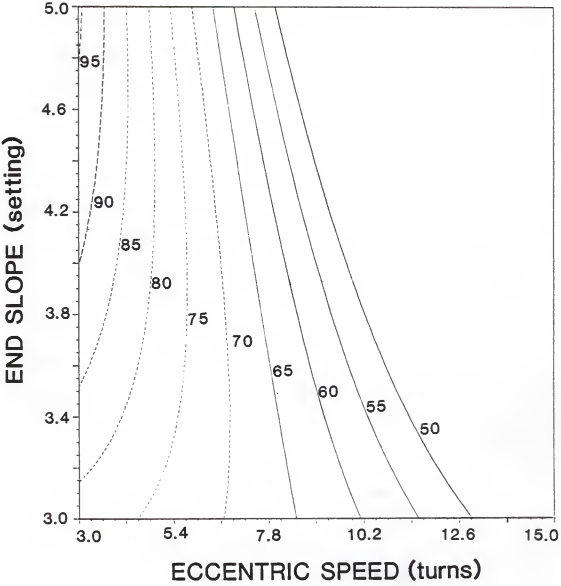

5.0
4.6
4.2
3.8
3.4
3.0
3.0
5.4
7.8
10.2
12.6
15.0
END SLOPE (setting)
ECCENTRIC SPEED (turns)
100
95
90
85
90
85
95
80
75
70
65
60
55
50

Fig. 6. Predicted values of percent germ recovered as affected by eccentric speed and end slope for wheat germ purified on a Fluidized-Bed Separator using side slope of 4.5 and air flow of 16.5.



5.0
4.6
4.2
3.8
3.4
3.0
END SLOPE (setting)
3.0
5.4
7.8
10.2
12.6
15.0
ECCENTRIC SPEED (turns)
100
95
90
85
80
75
70
65
60
55
50

Fig. 7. Predicted values of percent germ recovered as affected by eccentric speed and end slope for wheat germ purified on a Fluidized-Bed Separator using side slope of 4.5 and air flow of 18.


5.0
4.6
4.2
3.8
3.4
3.0
END SLOPE (setting)
95
90
85
80
75
70
65
60
55
50
3.0
5.4
7.8
10.2
12.6
15.0
ECCENTRIC SPEED (turns)

out of 10 separations yielded protein higher than 32%. However, over this range, none of the separations yielded 80% or higher germ recovery (Table 18). Only 3 out of the 10 separations yielded higher than 60% recovery.

Within the range of eccentric speed 8 to 11, as percent protein increased, percent germ recovered decreased (Figs. 8 and 9). Eccentric speed 10 gave the maximum protein and the minimum germ recovery at all air flow settings between 16 and 17. It was observed that increasing air flow affected germ recovery and percent protein differently at different eccentric speeds. Thus, 16.5 (the median air flow used) did not produce a median germ recovery or percent protein.

Further effort to maximize germ recovery and protein resulted in 8 out of 9 separations with protein higher than 32% and 7 out of 9 separations with germ recovery higher than 59% (Table 19). Of these, 6 out of 9 had both greater than 32% protein and greater than 59% germ recovery. Only three of these fell within the range of settings predicted by RSM for both air flow and eccentric speed.

SUMMARY

Extrusion. A variety of textural qualities may be obtained in extruded wheat germ-wheat starch rods by varying temperature, moisture, and level of wheat germ. As the wheat germ level was increased the rod changed from a highly expanded porous product at 10% germ to a dense, crunchy product at 20% and higher germ levels. Those characteristics were influenced by moisture and temperature. As moisture increased, apparent density increased and expansion decreased. As temperature increased, density decreased. Rod diameter also decreased, however, expansion was increased in the longitudinal direction. The increase in rate of flow accompanied by decreasing density

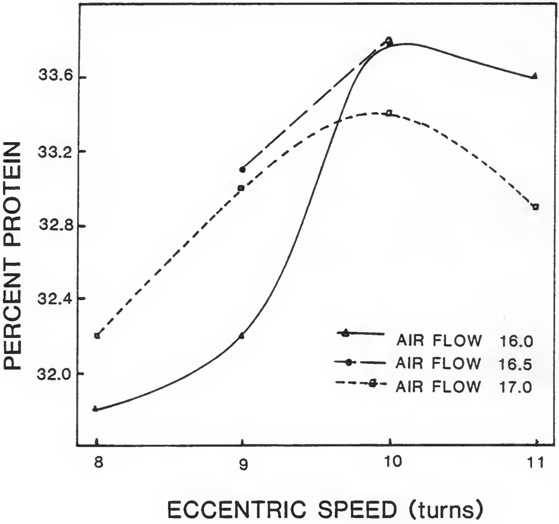
Table 18. Gravity Separation Over Ideal Range as Predicted by 4 and 2 Variable RSM Studies.

	Machine Settings		Purified Germ	
Trial	ECSP[a]	AIR	GM[b]	PROT
Control	---	---	---	30.3
1	8	17.0	77.34	32.2
2	8	16.0	79.08	31.8
3	9	17.0	43.70	33.0
4	9	16.5	39.31	33.1
5	9	16.0	63.14	32.2
6	10	17.0	29.50	33.4
7	10	16.5	29.48	33.8
8	10	16.0	33.25	33.8
9	11	16.0	35.21	33.6
10	11	17.0	30.87	32.9

[a] Independent variables: ECSP (eccentric speed), AIR (air flow), end slope and side slope set at 4.5

[b] Dependent variables: GM (% purified germ/total), PROT (% protein - dry basis)

Fig. 8. Effect of eccentric speed and airflow on percent protein of wheat germ separated on a Fluidized-Bed Separator using side slope and end slope of 4.5.



PERCENT PROTEIN
33.6
33.2
32.8
32.4
32.0
AIR FLOW 16.0
AIR FLOW 16.5
AIR FLOW 17.0
8
9
10
11
ECCENTRIC SPEED (turns)

Fig. 9. Effect of eccentric speed and airflow on percent germ recovered for wheat germ separated on a Fluidized-Bed Separator using side slope and end slope of 4.5.

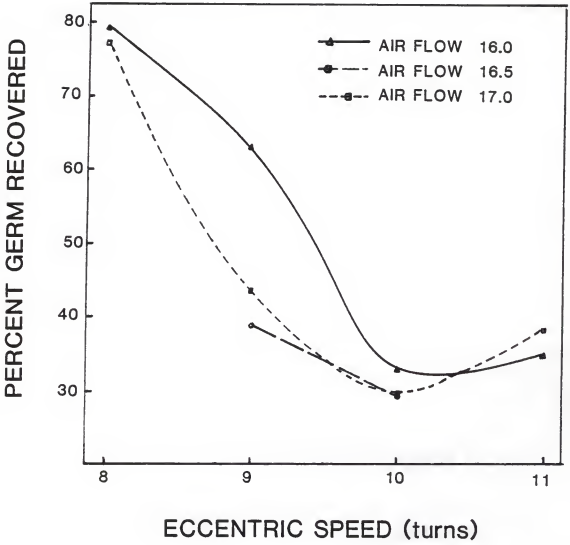

PERCENT GERM RECOVERED
80
70
60
50
40
30
AIR FLOW 16.0
AIR FLOW 16.5
AIR FLOW 17.0
8
9
10
11
ECCENTRIC SPEED (turns)

Table 19. Gravity Separation at Ideal Settings as Predicted by RSM, Graphing, and Observation.

	Machine Settings		Purified Germ	
Trial	ECSP[a/]	AIR	GM[b/]	PROT
Control	---	---	---	30.5
1	9.0	16.25	61	33.1
2	8.5	14.00	90	32.4
3	9.5	15.75	71	32.9
4	10.0	14.50	84	32.4
5	7.0	16.75	59	33.4
6	9.5	16.00	45	32.9
7	9.25	16.25	59	32.7
8	8.5	17.00	43	33.7
9	8.0	16.50	63	30.0

[a/]Independent variables: ECSP (eccentric speed), AIR (air flow), end slope and side slope set at 4.5

[b/]Dependent variables: GM (% purified germ/total), PROT (% protein - dry basis)

and rod diameter caused a great reduction in the grams per meter of extrudate as temperatures were increased. Thus, breaking strength was affected most significantly by temperature, with the breaking strength decreasing as the temperature was increased. Germ level and moisture also appeared to affect breaking strength, but to a much lesser extent.

Gravity Separation. It was possible to purify wheat germ to a level of 32.4% protein (dry basis) with 90% recovery of starting germ on the Fluidized-Bed Separator by using an eccentric speed of 8.5 with an air flow of 14.00. Higher percentages of protein could be obtained, but germ recovery suffered significantly. Only 43% germ was recovered at a protein level of 33.7%.

While there was some correlation between germ recovery and purity, it was possible to maximize either value without producing a large loss in the other by properly adjusting eccentric speed and air flow. Optimal ranges for obtaining high purity with high germ recovery were eccentric speed settings of 7 to 10 and air flow settings of 14 to 17 with end slope and side slope set at 4.5. Not all points within this range were ideal. Ideal settings were found with relative ease by setting the eccentric speed at various levels from 7 to 10 and adjusting air flow until a good separation was observed.

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PROPERTIES OF EXTRUDED WHEAT STARCH -
WHEAT GERM MIXTURES AS AFFECTED BY TEMPERATURE,
MOISTURE AND LEVEL OF WHEAT GERM

by

MARYSE FAY SCHULTZ

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A Brabender laboratory-scale single screw cooking extruder was used to extrude wheat starch-wheat germ mixtures at levels of 0, 10, 15, 20, 25, and 30% wheat germ (dry basis). Purified, stabilized, ground wheat germ at 7.1% moisture, 34.6% protein, 11.2% fat, and 4.7% ash, and commercial grade wheat starch were used. Moisture levels of 16, 17, 18, 19, 20.5, and 22% were tested using 3 different dies; two straight dies with areas of 0.38 cm^2 and 0.64 cm^2, and a die with a side orifice of 0.49 cm^2 were used.

The side die was most effective in preventing surging at high germ levels, while not exceeding power requirements at low germ levels. Moisture levels of 17, 18, and 19% were most effective in extruding rods using the side die. Temperatures of 150, 165, 175, 180, and 195°C at the final, or metering, zone were also tested for effect upon density (g/cc), expansion (diameter in mm), and breaking strength (kg to break a 15 cm rod over a 9 cm expanse), of extrudates.

When using the side die, as wheat germ level is increased, density increased; expansion increased to a level of 10% germ, at median temperatures, then decreased; no clear effect upon breaking strength was observed. As temperature was increased above 165°C, density decreased. Diameter decreased as temperature increased; however, the rate of extrusion increased, indicating an increase in expansion in the axial direction. Increased flow rate accompanied by decreasing density and diameter caused great reduction in grams per meter of extrudate as temperature increased, thus breaking strength was decreased as temperature increased. As moisture increased, density and expansion decreased; breaking strength increased at

germ levels below 25%, but decreased at 25 and 30% germ levels.

Purification of wheat germ was conducted using a laboratory size Fluidized-Bed Separator, or gravity separator. There are six variable settings on this machine: air flow, eccentric speed, end slope, side slope, feeding speed, and feed out gate position. A series of tests including two computer assisted RSM studies were used to determine the best settings for separation of bran from wheat germ. Protein level was used to determine germ purity. Starting germ had approximately 30.5% protein (dry basis).

Wheat germ could be purified to a level of 32.4% protein with 90% recovery, only 43% germ was recovered at protein levels of 33.7%. The optimal range of settings for germ purification were: end slope of 4.5, side slope of 4.5 (with 0 being the base and 5 being maximum slope), feeding speed of 7, air flow of 14 to 17 clockwise turns and eccentric speed of 7 to 10 turns. Not all settings within this range were ideal; however, ideal settings were found with relative ease by setting the eccentric speed at various levels from 7 to 10 and adjusting the air flow until good separation was observed.